Gallium Arsenide Monolithic Optoelectronic Circuits

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Gallium arsenide monolithic optoelectronic circuits

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Abstract

The optical properties of GaAs make it a very useful material for the fabrication of optical emitters and detectors. GaAs also possesses electronic properties which allow the fabrication of high speed electronic devices which are superior to conventional silicon devices. Monolithic optoelectronic circuits are formed by the integration of optical and electronic devices on a single GaAs substrate.

Integration of many devices is most easily accomplished on a semi-insulating (SI) substrate. Several laser structures have been fabricated on SI GaAs substrates. Some of these lasers have been integrated with Gunn diodes and with metal semiconductor field effect transistors (MESFETs). An integrated optical repeater has been demonstrated in which MESFETs are used for optical detection and electronic amplification, and a laser is used to regenerate the optical signal.

Monolithic optoelectronic circuits have also been constructed on conducting substrates. A heterojunction bipolar transistor driver has been integrated with a laser on an n-type GaAs substrate.

Introduction

This paper reviews our recent progress in the development of GaAs-based monolithic optoelectronic circuits. The first section describes laser structures which have been fabricated on SI GaAs substrates. The non-conducting substrate allows for simple electrical isolation of the laser from other electronic devices on the chip. The second section describes several optoelectronic circuits which have been fabricated on SI substrates. The third section describes an integrated optoelectronic process which combines lasers with bipolar transistors on conducting n^+ - GaAs substrates.

Lasers on Semi-Insulating Substrates

Conventional injection lasers are fabricated on conducting n-type substrates. The current flows vertically from the p-side down through the substrate. The current flow is generally confined to a narrow region by some form of stripe contact. Lasers on n-type substrates are generally bonded upside down to improve their thermal dissipation. For certain low threshold lasers, heat sinking may be performed through the substrate because of their low power dissipation. When constructing a monolithic optoelectronic circuit, it is imperative that the chip be mounted right side up.

The electrical isolation provided by a SI substrate reduces leakage current in laser structures in which the current flows laterally rather than vertically. In the laterally diffused junction laser[1] (also known as the TJS laser) shown in Figure 1 current flows laterally across the p-n junction in the GaAs layer. Negligible amounts of current pass through the GaAlAs cladding layers because of the larger bandgap of that material. Excellent performance has been obtained for this structure in terms of low threshold current, single mode operation, and long lifetime.[1,2]

Another approach to fabricating lasers on SI substrates is to employ a vertical p-n junction but to provide lateral current flow through an n-type GaAs layer. The simplest such configuration is the crowding effect laser[3] shown in Figure 2. Current flows vertically through the double heterostructure and laterally through the n-GaAs layer which lies just below the double heterostructure. Current is confined to the immediate vicinity of the mesa edge by the voltage drop which results from the resistivity of the n-GaAs layer. Leakage current can be reduced in this structure by etching the mesa into the shape of a T to form a T-laser.[4] A low mesa version of the T-laser is shown in Figure 3. In the low mesa T-laser, the active layer also serves as the n-type contact layer.

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Another laser structure which has been fabricated on a SI substrate is the Be-implanted stripe laser[5] shown in Figure 4. All the layers are grown initially n-type. The top GaAlAs layer is converted to p-type by a selective implantation of Beryllium. Threshold currents as low as 15 mA have been obtained for a cavity length of 100 μm.

The buried heterostructure laser has also recently been fabricated on a SI substrate.[6] The structure is shown schematically in Figure 5. CW operation is easily obtained because of the low threshold current for this type of laser. For a 300 μm long device the threshold current is 8 mA per micron of stripe width. The performance of the buried heterostructure laser on a SI substrate in terms of threshold current, differential quantum efficiency and mode stability is comparable to the performance of the buried heterostructure lasers on n^+ substrates.

The die size of a monolithic optoelectronic circuit using the above mentioned lasers is limited in one dimension by the laser cavity length. One approach which avoids this limitation is to form laser cavities which are curved into quarter circles or semi-circles.[7] These so-called "whispering gallery" lasers are shown in Figure 6.

Optoelectronic Circuits on SI Substrates

Monolithic optical transmitters can be envisioned in which electronic devices are used to perform logic, multiplexing, and driving functions, and a laser is used as the optical source. To demonstrate the feasibility of integrating a laser with electronic devices, various lasers were integrated with electronic drivers consisting of either a Gunn diode or a metal semiconductor field effect transistor (MESFET).

In the first such demonstration, a crowding effect laser was integrated with a Gunn diode connected in series[8] which was operated as a free-running oscillator. The laser output was modulated by the Gunn diode at a frequency of 750 MHz. This initial demonstration was followed by the integration of a T-laser with a MESFET[4] and a Be-implanted laser with a MESFET.[5] In both cases the laser output could be directly modulated by means of the gate voltage.

A complete optical repeater was fabricated on a single GaAs substrate. The repeater is illustrated in Figure 7, and its schematic circuit is shown in Figure 8. The repeater consists of three transistors and a crowding effect laser. Transistor Q_1 is connected as a current source, Q_2 is the optical detector, and Q_3 is the laser driver. The laser was biased just above threshold by an external current source. The detector was illuminated with light from an external GaAlAs laser through an optical fiber. The overall optical gain of the repeater was 10 dB.

Optoelectronic Circuits on Conducting Substrates

We have recently developed a process for the fabrication of injection lasers on n^+ - GaAs substrates which is compatible with the fabrication of heterojunction bipolar transistors.[10] A schematic illustration of the combined transistor-laser device is shown in Figure 9. The left half of the device forms the transistor and the right half of the device forms the laser. The two halves of the device are identical, but differ only in the way they are electrically connected. In the transistor, the top n-GaAlAs layer operates as a wide band-gap emitter. The thin GaAs base layer is contacted by means of a Be-implanted and diffused p-type region. In the laser half of the device, no contact is made to the top GaAlAs layer, and the Be-implanted contact becomes the laser anode.

With the transistor and laser connected as shown in Figure 10, the laser current can be controlled by means of the base current. Pulsed threshold currents for the lasers were as low as 55 mA for a 250 μm cavity length. CW thresholds were about 20 percent higher than the pulsed thresholds. The transistors exhibited betas in excess of 900. The rise time of the transistor driven laser was measured to be 1.1 nsec.

Conclusion

The first steps have been taken toward the development of monolithically integrated optoelectronics circuits on GaAs substrates. The reduction of parasitic reactances afforded by monolithic integration should be able to increase speed and decrease noise in optoelectronic systems. Monolithic optoelectronic integration also has the potential of improving a system's reliability, while decreasing its cost.

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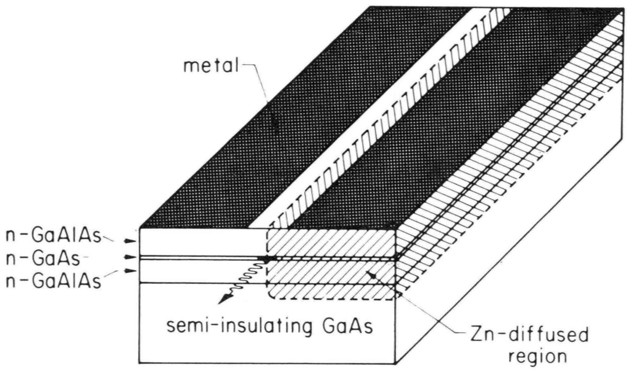

Figure 1.

A laterally diffused junction laser

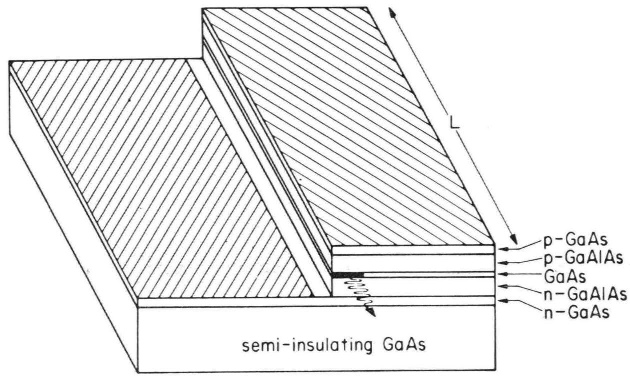

Figure 2.

A crowding effect laser

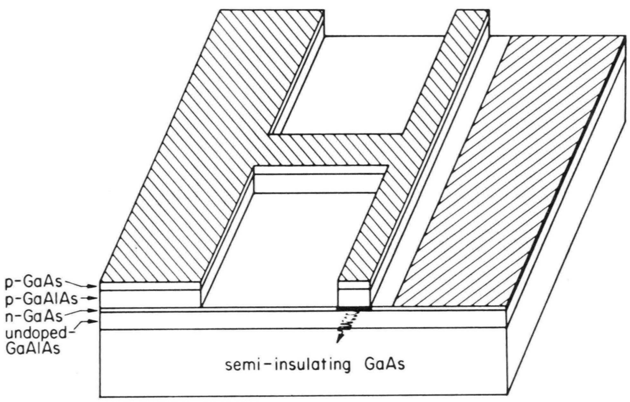

Figure 3.

A low mesa T-laser

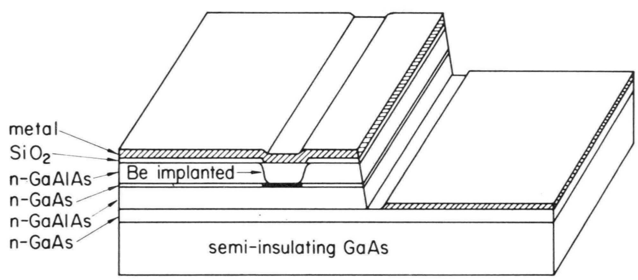

Figure 4.

A Be-Implanted laser

on a semi-insulating substrate

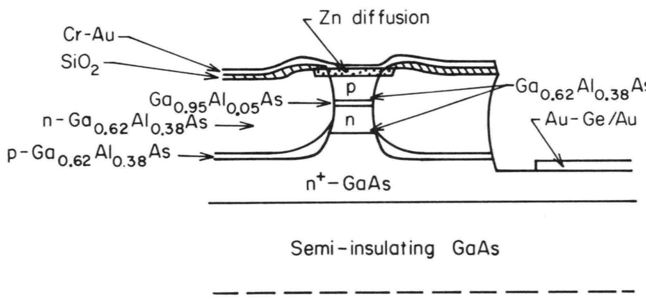

Figure 5.

A buried heterostructure laser on a semi-insulating substrate

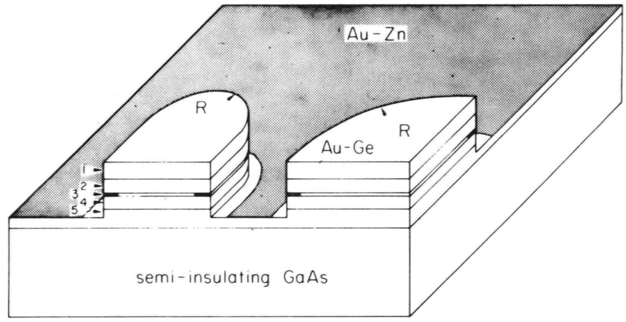

Figure 6.

A quarter-ring and a half-ring whispering gallery laser

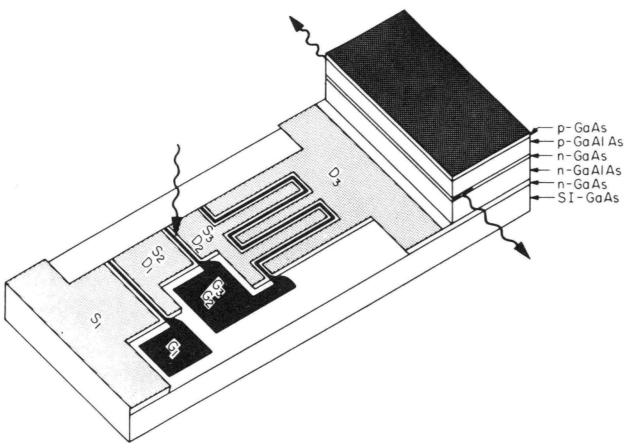

Figure 7.

An integrated optical repeater

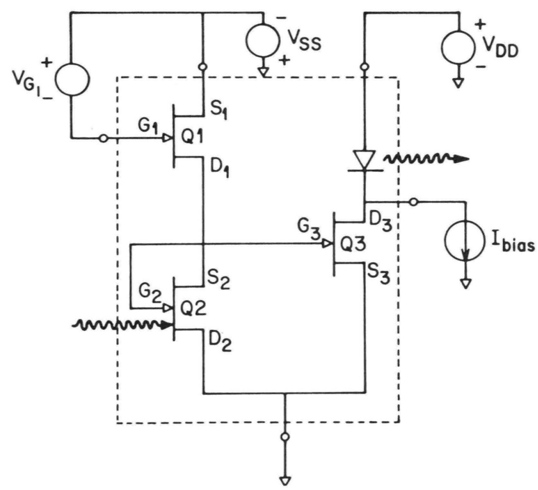

Figure 8.

Schematic circuit diagram of the repeater

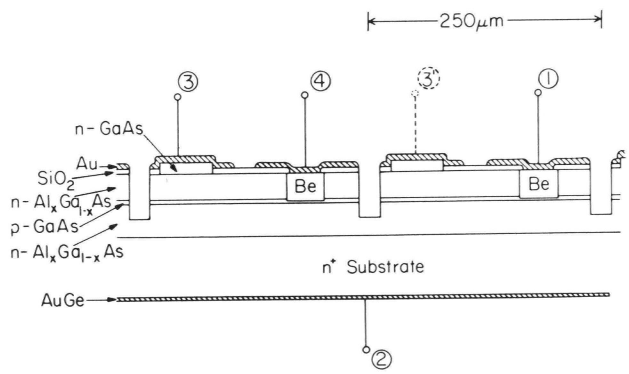

Figure 9.

A laser with an integrated bipolar transistor

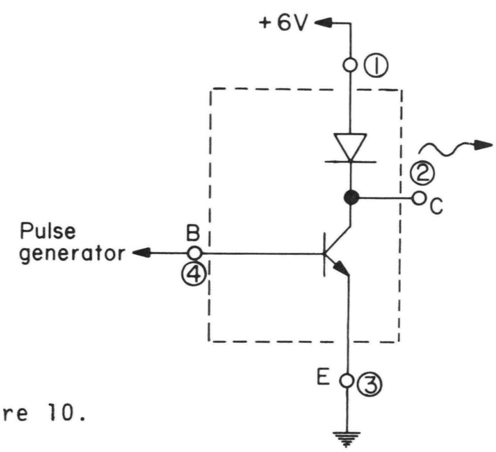

Figure 10.

Schematic circuit diagram of the integrated laser-transistor